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Sampling in Space and Time for Natural Resource Monitoring

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Monitoring is defined as collecting information on an object through repeated or continued observation in order to determine possible changes in the object. The monitoring object may have or may not have a spatial extent. If it has, then observations can be collected via sampling in space-time, the subject of this presentation. An example of an object without spatial extent is a point in a river where the water quality or level is measured repeatedly: an example of sampling in time. The implementation of international agreements such as the Kyoto Protocol and, at the European level, the Soil Thematic Strategy, the Water Framework Directive and the Habitats Directive ask for efficient sampling methods for monitoring natural resources such as soil, groundwater, surface waters and biotic populations.

It is useful to distinguish three categories of monitoring according to its aim:

1. status monitoring for quantitative description of the universe as it changes with time;
2. trend monitoring to decide whether temporal trends are present in the universe;
3. regulatory or compliance monitoring to decide whether the universe satisfies regulatory conditions.

An important choice in sampling is between design-based and model-based sampling. In design-based sampling the sampling units are selected at random, more specific by probability sampling. In model-based sampling the units are selected purposively, for instance by minimizing a quality measure defined in terms of the distances between the sampling units or in terms of the prediction-error variances. The appropriateness of these two approaches is partly determined by the aim of monitoring. In regulatory monitoring the validity of the result (conclusion of hypothesis testing) is of great importance, and therefore design-based methods are more appropriate. In status and trend monitoring the appropriateness is partly determined by the target quantity. For mapping the current values (values at latest sampling time) or the temporal trend at points, model-based methods are the best option, whereas for estimating the current spatial mean or the spatial mean temporal trend a design-based approach is preferable.

The efficiency (precision and costs) of a sampling pattern for monitoring is partly determined by the distribution of the sampling units in the space-time universe. An important aspect of the sampling pattern for monitoring is whether at all sampling times the same locations are observed, or whether this restriction is relaxed and all or part of the sampling locations is replaced by new locations. Based on this aspect four basic types of sampling pattern are distinguished: *static, synchronous, static-synchronous* and *rotational* patterns. In *Static Sampling* all sampling takes place at a fixed set of locations. Sampling at the various locations may or may not follow the same pattern in time. In *Synchronous Sampling*, also referred to as dynamic sampling, a different set of sampling locations is selected for each sampling time. The spatial patterns used at different times may or may not be the same. If they are the same, then they do not coincide spatially, because otherwise the pattern would be static-synchronous. When Static Sampling and Synchronous Sampling are combined with each other, we speak of *Static-Synchronous Sampling*. *Rotational Sampling* is a compromise between Static Sampling and Synchronous Sampling, in the sense that the locations of the previous sampling time are partially replaced by new ones. The choice of a pattern type for monitoring should be guided by statistical as well as operational considerations, which will be dealt with in this presentation.

For a more complete design of a sampling pattern for monitoring, one must also specify the spatial and temporal patterns describing the distribution of the sampling units in space and in time, respectively. This leads for instance to the following descriptions: 1) Synchronous Sampling with Random Grid Sampling in space and Stratified Simple Random Sampling in time; 2) Static-Synchronous Sampling with Centred Grid Sampling in space and Systematic Sampling in time.

The process of designing efficient sampling patterns will be illustrated with real-world case studies on soil and groundwater monitoring.

References

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